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Bottom Backscattering Measured Off the Carolina Coast During the Littoral Warfare Advanced Development 98-4 Experiment

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Measurements of ocean bottom backscattering were performed in a shallow water environment off the South Carolina coast as part of the Littoral Warfare Advanced Development 98-4 Experiment. Scattering strengths were obtained at 2., 2.5, 3., and 3.5 kHz as a function of grazing angle. Scattering strengths show no clear frequency dependence. Bottom backscattering measurement results are consistent with measurements taken at nearby sites from previous LWAD (FTE 96-2 and SCV 97) experiments.

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BOTTOM BACKSCATTERING MEASURED OFF THE CAROLINA COAST DURING THE LITTORAL WARFARE ADVANCED DEVELOPMENT 98-4 EXPERIMENT

INTRODUCTION

The Littoral Warfare Advanced Development (LWAD) 98-4 experiment was conducted off the South Carolina coast in September 1998. Bottom reverberation is a potential source of clutter for active sonar systems operating in this littoral area. Bottom backscattering strength (BSS) in the 2 to 3.5 kHz band was calculated using direct path measurements.

The bottom interaction problem can involve multiple physical processes, all of which may contribute to the measured scattering strength: scattering from the water/sediment interface, scattering in the sediment volume itself, or scattering from the basement or a subsurface layer with a significant impedance mismatch. The frequency and grazing-angle dependence can reflect an enhancement of one mechanism over another, and given the variability of the littoral environment in sediment thickness, composition, and frequency-dependent attenuation, correct physical interpretation of bottom scattering strengths usually requires significant knowledge of the geoacoustic properties and structure of the subbottom. For regions where sand cover tends to be significant and results depend on specific characteristics such as sand layer thickness and homogeneity, there is greater potential for variability in frequency and site dependence.

Bottom scattering strength can be calculated by solving the sonar equation in the following form:

$$BSS = RL - SL + TL_s + TL_r - 10\log A \tag{1}$$

where BSS is the scattering strength in dB, RL is the measured reverberation level in dB *re* $(1\mu\text{Pa})^2/\text{Hz}$, SL is the source level in dB *re* $(1\mu\text{Pa})^2/\text{Hz}$ at 1 m, TL_s is the transmission loss from the source to the ensonified patch on the bottom in dB, TL_r is the transmission loss from the ensonified patch on the bottom to the receiver in dB, and A is the area of the ensonified patch in square meters.

During LWAD 98-4, data were obtained at four frequencies (2, 2.5, 3, 3.5 kHz) covering grazing angles of 5 to 28 degrees. BSS data during four scattering runs were collected at three sites shown in Figure 1 and described in Table 1. The scattering sites (Run 1, Runs 2 and 4, Run 3) are located near the LWAD 98-2 test plan points ZL, ZLM, and ZLS respectively. Scattering sites R, B, Q, and C from LWAD experiment FTE 96-2 are shown on the map in Figure 1. Depths are in meters. Scattering sites NS, NR, SR1, SR2, and SR3 from LWAD experiment SCV 97 are also shown in the figure. The dashed line approximately separates the region consisting of a rock bottom and

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Table 1 — LWAD 98-4 Scattering Sites

Run #	Date	Time (Z)	Site Location (Latitude (deg), Longitude (deg))
1	28 Sep 1998	1532-1538	32.863 N 77.994 W (near ZL)
2	30 Sep 1998	0759-0806	32.657 N 78.181 W (near ZLM)
3	30 Sep 1998	1427-1433	32.540 N 78.459 W (near ZLS)
4	30 Sep 1998	1815-1822	32.646 N 78.189 W (near ZLM)

the region with a sand covered bottom. Scattering Run 1 with a water depth of 166 m and with a sand covered bottom occurred between sites NS and NR, approximately 4.5 nm from site NS and approximately 5 nm from site NR. Scattering Run 3 with a water depth of 189 m and a limestone bottom with minimal sand cover is approximately 2 nm from site SR2. Scattering Runs 2 and 4 had a water depth of 207 m and a limestone bottom and are located approximately 7 nm from site SR1 and approximately 7 nm from site Q.

Bottom backscattering measurements have been performed during four previous LWAD experiments: Focused Technology Experiment 96-2 (FTE 96-2), Focused Technology Experiment 97-2 (FTE 97-2), System Concept Validation 97 (SCV 97), and LWAD Experiment 98-2 (LWAD 98-2). The FTE 96-2 and SCV 97 backscattering measurements appear in [1,2]. FTE 97-2 data were collected at a site 16 nm southwest of Key West, Florida and the results are reported in [3]. LWAD 98-2 data were collected 120 nm west of Key West, Florida and are reported in [4].

LWAD BSS measurements have shown a strong dependence in scattering strength level on the presence or absence of a significant sand layer (> 20 m). Data taken with a significant sandy sediment thickness can be fit well by assuming a scattering strength proportional to the sine of the grazing angle, with proportionality constants of -25 dB to -30 dB. However, when the sediment is negligible and the underlying limestone is the scatterer, BSS values are 15-20 dB higher [4]. This report compares the LWAD 98-4 results with the FTE 96-2 and SCV 97 data collected in the same area off the South Carolina coast.

EXPERIMENT GEOMETRY AND DATA ANALYSIS

The bottom scattering tests were conducted from the research vessel SEA DIVER during LWAD 98-4. A 16-hydrophone vertical line array (VLA) and a source were deployed on a single cable, with the source 4 m above the center of the VLA receiving aperture. This produces a nearly monostatic measurement geometry.

The source was a ring-shaped transducer (USRD G81) that gave maximum (over the range of launch angles) root-mean-square source levels ranging from 194 dB (2000 Hz) to 197 dB (2500 Hz). The source beam pattern features a null in the upward direction and some flattening in the downward direction. This beam pattern gave maximum source level for all of the launch directions used to calculate scattering strength, so the deviations from the omnidirectional pattern did not affect the BSS calculation. However, the source directionality does help to mitigate sidelobe interference for very high grazing-angle returns, such as the initial acoustic interactions with the ocean surface and bottom. This allows extension of data validity to lower grazing angles. During the runs, the source was placed at a depth of approximately 75 m. The waveforms were 50 ms gated continuous wave (GCW) signals. Sets of 20 identical wavetrains consisting of four adjacent signals in the sequence 2.0, 3.0, 2.5, and 3.5 kHz were transmitted. The wavetrains were separated by 15 s.

The bottom reverberation from the 50 ms pulses was received on the 16-hydrophone VLA. The hydrophones were spaced at 15.24 cm (6 in) which corresponds to half-wavelength spacings of 4920 Hz. Data processing demonstrated that the response from only four phones was satisfactory. Interpolation processing recovered two additional phones. Seven beams with cosine-spaced main response axes were formed from the 6-phone aperture, with most of the returns coming from a downward directed beam with angle approximately 70 degrees relative to bottom endfire.

After beamforming, power spectra were obtained by performing 50 ms Fourier transforms with 50 percent overlap over the length of the reverberation time series. A frequency band representing the total energy about the zero-Doppler peak was selected, and a time series including only the energy in this band was created for each ping. The direct arrivals for the pings were then temporally aligned and the various pings were averaged to produce a single reverberation curve for each beam and frequency bin. Integration over the roughly zero-Doppler spectral peak produced the total returned power as a function of time and beam. By calculating geometric spreading loss along each ray path, the transmission loss terms to and from the scattering patch were obtained. Finally, the computed beam pattern and raytrace were used to calculate the scattering patch area. From these inputs, BSS was calculated using Eq. (1) as a function of beam, frequency, and grazing angle. The standard deviations due to ping-to-ping variability within the sets of identical transmissions were ± 2 to 3 dB. The system calibration was computed to within 1 dB accuracy.

BOTTOM SCATTERING RESULTS

Figure 2 shows the BSS values from the four LWAD 98-4 scattering runs at 2, 2.5, 3, and 3.5 kHz as a function of grazing angle. The source was at a depth of approximately 75 m. The grazing angles for the source-to-scatterer and scatterer-to-receiver are similar (i.e., within tenths of a degree), so only one angle needs to be considered in the analysis. The average of the two grazing angles is the quantity plotted on the x-axis. The scattering measurements are averaged over a set of 20 pings from the downward directed beam with angle approximately 70 degrees relative to bottom endfire. The points marked with squares are BSS values from Run 1 located near ZL. The average BBS value from Run 1 is approximately -29 dB. The empty circles mark BSS values from Runs 2 and 4 in the vicinity of ZLM with an average value of approximately -19 dB. The filled circles mark BSS values from Run 3 near point ZLS having an average value of approximately -25 dB. The scattering strengths measured during the four runs showed no frequency dependence. Grazing angles ranged from 5 to 28 degrees. The bottom bold curve in the figures is the Mackenzie curve $-27 + 10\log(\sin^2\theta)$, a reference curve showing Lambert's law with a coefficient of -27 dB. This curve is the standard input to Navy performance models, with the selection of the -27 dB value originating in the work of Mackenzie [5].

Figures 3-5 shows the LWAD 98-4 BSS values at 2, 2.5, 3, and 3.5 kHz as a function of grazing angle compared with BSS values from nearby sites obtained during the LWAD FTE 96-2 and SCV 97 experiments. Figure 3 shows the BSS values from Run 1 (near point ZL) marked with empty circles compared with the BSS values obtained from the LWAD SCV 97 sites NR (empty squares) and NS (solid circles). Site NR has a limestone bottom and produces an average BSS value of -21 dB. Site NS has a sand covered bottom with an average BSS value of -35 dB. Figure 1 shows the Run 1 site is in the region with a sand covered bottom. Figure 3 shows that the Run 1 BSS values have an average value of -29 dB.

Figure 4 shows the BSS values from Run 3 (near point ZLS) marked with empty circles compared with the BSS values obtained from LWAD SCV 97 site SR2 (solid circles) and LWAD FTE 96-2 sites B (empty triangles) and C (empty squares). Site SR2 has a limestone bottom with a minimal cover of sand producing an average BSS value of -24 dB. LWAD FTE 96-2 site B has a sand bottom with an average BSS value of -29 dB. LWAD FTE 96-2 site C has a limestone bottom with an average BSS value of -18 dB. (LWAD FTE 96-2 site Q produced BSS values equal to the BSS values of site C.) Run 3 BSS values have an average value of -25 dB. This value agrees closely with the average BSS value (-24 dB) from nearby site SR2.

Figure 5 shows the BSS values from Runs 2 and 4 (near point ZLM) marked with empty circles compared with the BSS values obtained from LWAD SCV 97 sites SR1 (deep) and SR1 (shallow) and LWAD FTE 96-2 sites B and C. The BSS values from site SR1 (deep) are marked with solid circles and the BSS values from site SR1 (shallow) are marked with empty triangles. The BSS values from Site C are marked with empty squares and the BSS values from Site B are marked with solid triangles. Site SR1 (deep) has a limestone bottom producing an average BSS value of -21 dB. Site SR1 (shallow) has a sand bottom producing an average BSS value of -27 dB. Recall that LWAD FTE 96-2 sites C and Q have a limestone bottom with an average BSS value of -18 dB and that LWAD FTE 96-2 site B has a sand bottom with an average BSS value of -29 dB. Runs 2 and 4 BSS values have an average value of -19 dB. This value agrees closely with the average BSS value of nearby site Q (-18 dB) and site SR1 (deep) (-21 dB) having a limestone bottom.

Table 2 presents an overview of the BSS values obtained at the various sites. Sites (Q, C, LWAD 98-4 Runs 2 and 4, NR and SR1 [deep]) with a limestone bottom produce BSS values in the range -18 to -21 dB. The BSS values from the sites (SR1 [shallow], B, LWAD 98-4 Run 1 and NS) with a sand bottom are in the range -27 to -35 dB. Intermediate values of -24 dB and -25 dB are obtained at sites (SR2 and LWAD 98-4 Run 3) having a bottom of limestone with minimal sand cover.

SUMMARY

During LWAD 98-4, bottom backscattering strengths were measured at three sites ZL, ZLM and ZLS off the coast of South Carolina. The water depths at these sites ranged from 166 to 207 m. The sites had bottom types that were either limestone, limestone with minimal sand cover, and limestone with significant sand cover.

The scattering strengths measured during the four runs were in the -19 to -29 dB range and showed no frequency dependence. Grazing angles ranged from 5 to 28 degrees. Runs 2 and 4 occurred in the vicinity of point ZLM where the bottom type is limestone and BSS values are approximately -19 dB. Run 1 occurred in the vicinity of point ZL where the bottom has significant sand cover and BSS values are approximately -29 dB. Run 3 occurred in the vicinity of point ZLS where the bottom is limestone with some sand cover and BSS values are approximately -25 dB.

Table 2 — Bottom Backscattering Results for FTE 96-2, SCV 97 and LWAD 98-4 Sites

Site	Bottom Type	BSS Values (dB)
Q	Limestone	-18
C	Limestone	-18
LWAD 98-4 Run 2	Limestone	-19
LWAD 98-4 Run 4	Limestone	-19
NR	Limestone	-21
SR1 (deep)	Limestone	-21
SR2	Limestone with sand	-24
LWAD 98-4 Run 3	Limestone with sand	-25
SR1 (shallow)	Sand	-27
B	Sand	-29
LWAD 98-4 Run 1	Sand	-29
NS	Sand	-35

Bottom backscattering measurements results from LWAD 98-4 were consistent with measurements taken at nearby LWAD FTE 96-2 and SCV 97 sites (Q, C, NS, NR, SR1 and SR2.)

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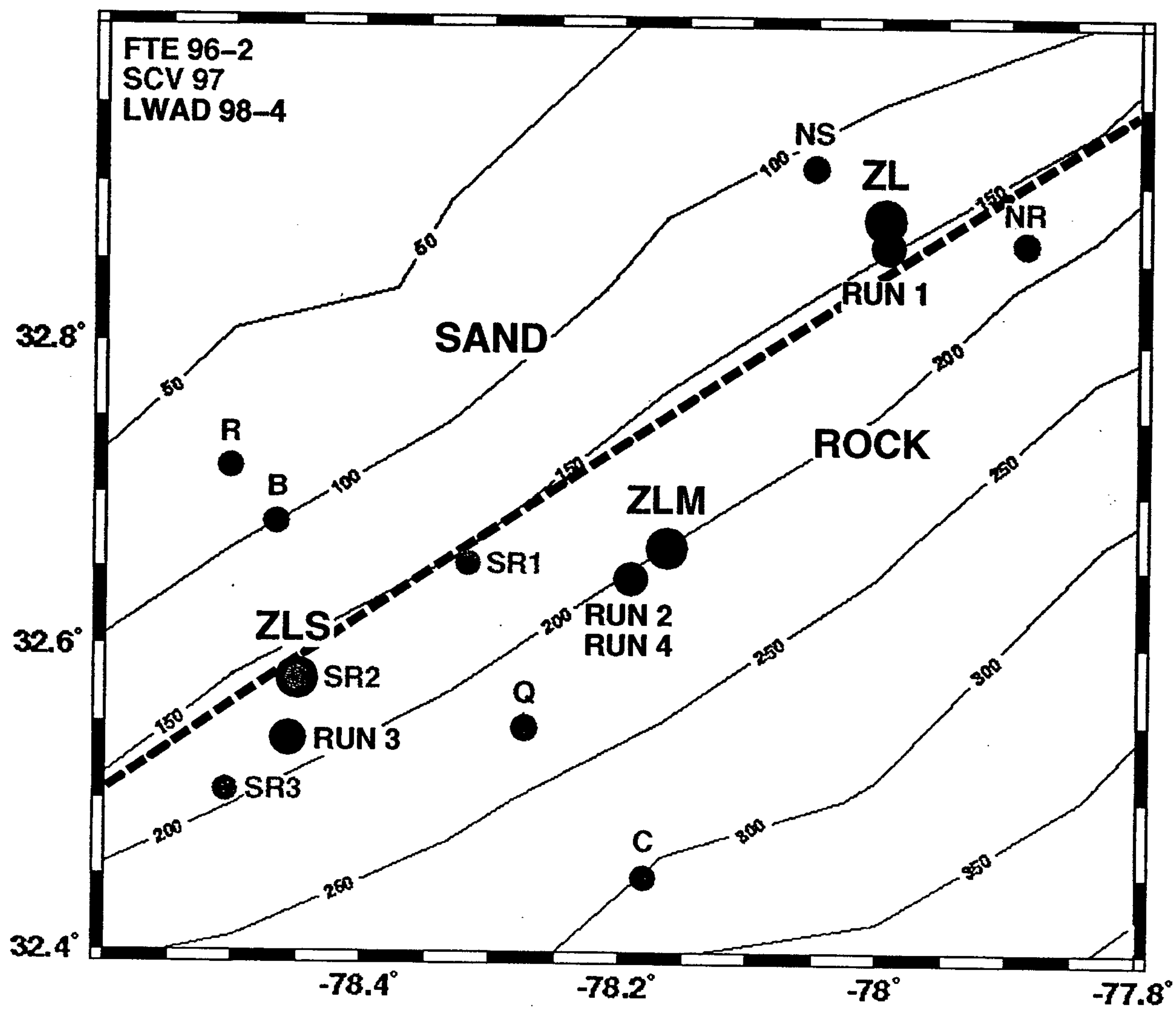

Fig. 1 — LWAD 98-4 bottom scattering experimental sites. The scattering sites labeled Run 1, Run 2, Run 3 and Run 4 are located near sites ZL, ZLM, and ZLS. Scattering sites R, B, Q, and C from LWAD experiment FTE 96-2 are shown on the map. SCV 97 scattering sites NS, NR, SR1, SR2, and SR3 are also shown. The dashed line approximately separates the sand and rock regions. Depths are in meters.

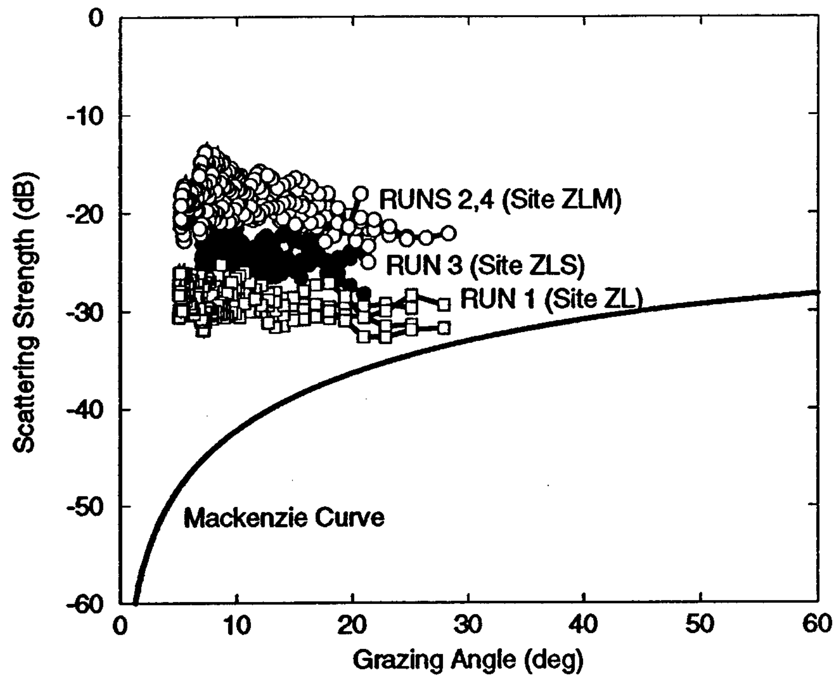

Fig. 2 — Bottom backscattering strength as a function of grazing angle for 2., 2.5, 3., and 3.5 kHz during scattering Runs 1 (empty squares), 2 (empty circles), 3 (solid circles), and 4 (empty circles) at sites ZL, ZLS, and ZLM.

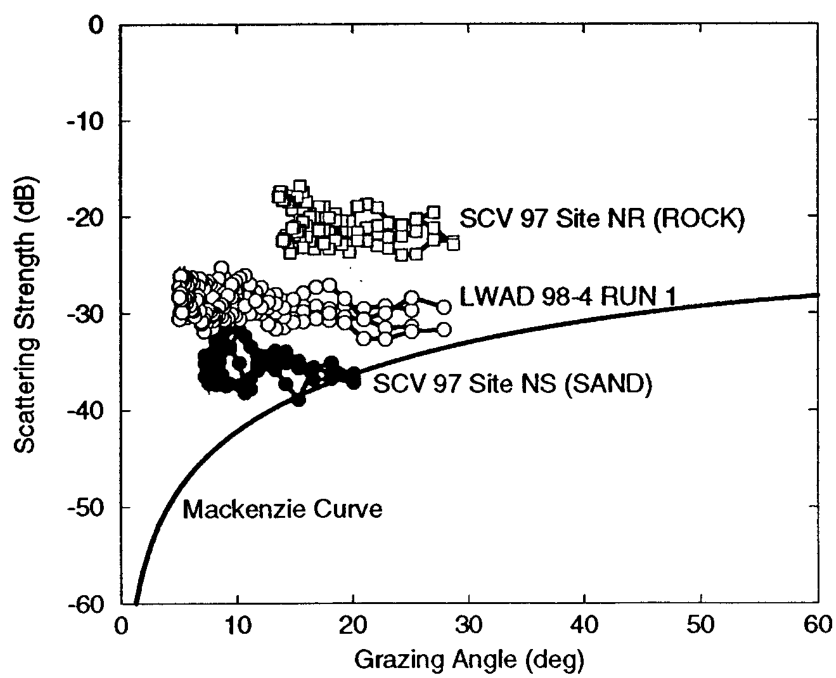

Fig. 3 — Bottom backscattering strength as a function of grazing angle for 2., 2.5, 3., and 3.5 kHz at scattering sites NR and NS during SCV 97 experiment and LWAD 98-4 experiment Run 1 (empty circles) near site ZL.

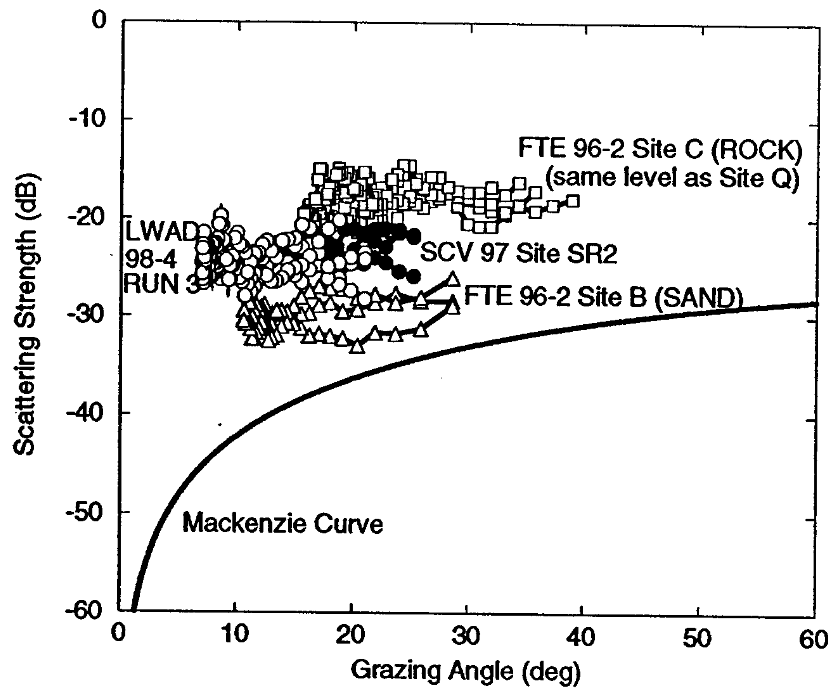

Fig. 4 — Bottom backscattering strength as a function of grazing angle for 2., 2.5, 3., and 3.5 kHz at scattering sites B and C during the LWAD FTE 96-2 experiment, LWAD SCV 97 experiment scattering site SR2, and LWAD 98-4 experiment Run 3 (empty circles) near site ZLS.

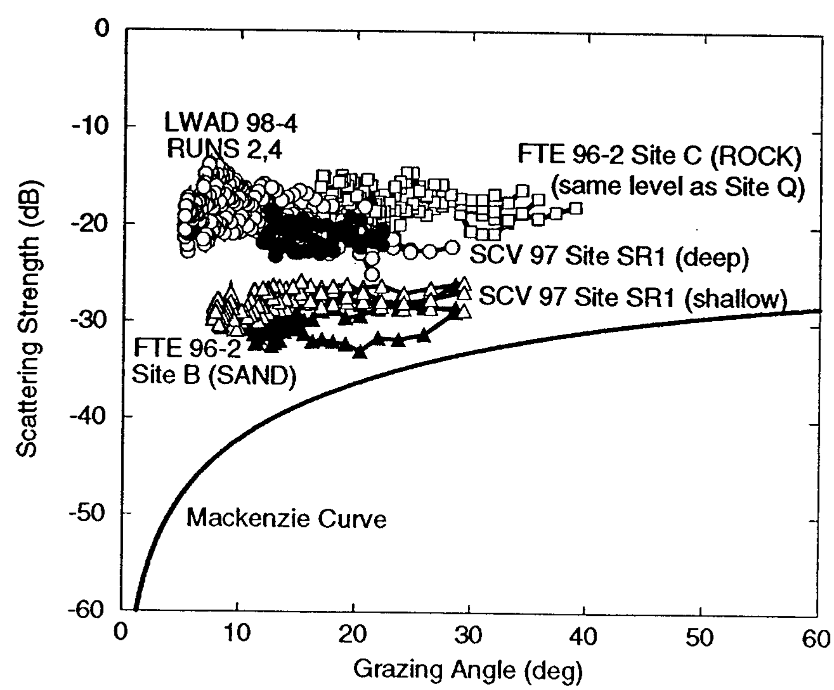

Fig. 5 — Bottom backscattering strength as a function of grazing angle for 2., 2.5, 3., and 3.5 kHz at scattering sites B and C during the LWAD FTE 96-2 experiment, LWAD SCV 97 experiment scattering site SR1 (deep and shallow), and LWAD 98-4 experiment Runs 2 and 4 (empty circles) near site ZLM.